doi: 10.14355/fiee.2016.05.002

Influence of Climate And Grazing on NDVI in a Typical Steppe Region in Inner Mongolia, China

Haimei Wang[1], Zhenghai Li[2], Guodong Han[3]

[1]Inner Mongolia Ecological and Agricultural Meteorology Center, Hohhot, Inner Mongolia, China

[2]College of Environment and Resources, Dalian Nationalities University, Dalian, Liaoning, China

[3]Inner Mongolia Agricultural University, Hohhot, Inner Mongolia, China

[1] wanghmhuhe@126.com; [2] li-lzhh@263.net; [3] nmghanguodong@163.com

Abstract

Based on temperature and precipitation data from 15 meteorological stations and data on livestock populations, we digitized spatial data related to climate aridity and livestock density in Xilingol Leauge, a typical steppe region of northern China, and analyzed the relationships among vegetation cover change (as measured by NDVI), aridity and grazing activity. The results show that: (1) the spatial pattern of the relationship between NDVI and the de Martonne aridity index (I_{dM}) was positive in most parts of Xilingol League; (2) livestock density increased from northwest to southeast, with 53.2% of the study area having livestock density of 40-80 standard sheep units/km2; (3) there was a binomial regression relationship between NDVI and livestock density, with higher livestock density that was concentrated in areas where the NDVI value ranged from 0.46 to 0.62; (4) there was complex linear correlation among NDVI, I_{dM}, and livestock density; (5) partial correlation analysis revealed a significant negative correlation between livestock density and NDVI, and a positive correlation between I_{dM} and NDVI, and the influence of aridity on NDVI was considerably greater than that of livestock density.

Keywords

Climate Change; Drought Index; Livestock Density; NDVI

Introduction

The Xilingol Steppe is located in central Inner Mongolia and forms part of the eastern Asia grassland subregion of the Eurasian grassland region. This natural grassland supports several abundant native vegetation and grassland types, and most of it is protected and intact. The grasslands and climate of the Xilingol Steppe support several sensitive and fragile ecosystems and provide ecological stability for this region of China. Climate change and intense human activities are impacting the grassland ecosystems in this region. As shown by earlier studies, these fragile grasslands are susceptible to damage and degradation if they are managed unsustainably, and over the last several decades the grasslands have suffered from degradation.

In recent decades, Chinese and foreign researchers have conducted extensive research related to grassland degradation, showing that 18%, 39%, 60% and 73% of the grassland area in Inner Mongolia had experienced significant degradation by the 1960s, 1980s, 1990s and the 2000s, respectively. The fact that the grasslands of Inner Mongolia have experienced degradation is indisputable.

In light of this situation, we used data related to de Martonne's aridity index (I_{dM}), climatic conditions, and livestock density to characterize the influence of human activity on grassland vegetation cover, as represented by the normalized difference vegetation index (NDVI).

Human activities in pastoral regions can be represented by livestock numbers, and the spatial distribution of livestock can reflect the effects of grazing on grassland ecology. Past research on the impact of grazing intensity on the health of grassland ecosystems has focused on the community and ecosystem levels, primarily using experimental plots to study the influence of variations in grazing intensity on soil, vegetation, microclimate and environment.

However, few research studies based on remote sensing technology have been designed to analyze the effects of human activities on grassland degradation. We digitized spatial data on livestock using Kriging's interpolation method, and referring to the population density interpolation method, we used the locations of residential areas and administrative divisions of towns as weight factors.

The objectives of this study are to use meteorological and NDVI data along with statistical data on livestock distribution to examine how climatic variables and grazing activities affect grassland vegetation cover. Our aim is to gain the understanding of natural and man-made mechanisms that drive change in this grassland ecosystem. The findings of the study will be applied to develop scientific strategies and programs for grassland restoration, management and use patterns.

Data and Study Methods

Meteorological and Statistical Data

Climatic data was obtained from 15 meteorological observation stations in Xilingol League (Figure 1), and statistical data on livestock numbers was obtained from county statistical reports.

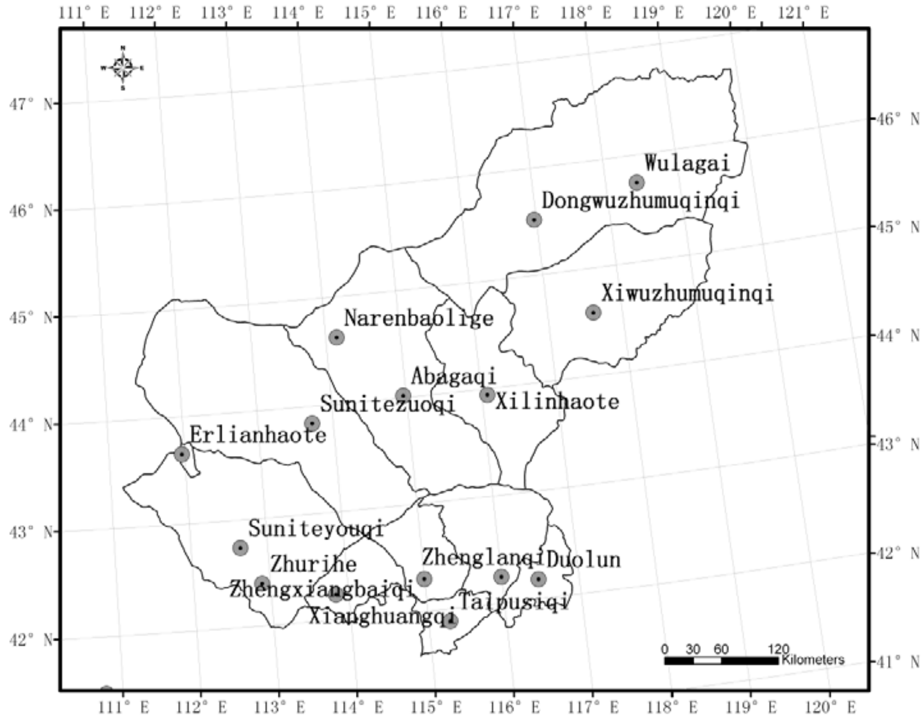

FIG. 1 VICINITY MAP OF WEATHER STATIONS IN THE STUDY AREA.

NDVI Data

A Normalized Difference Vegetation Index (NDVI) was used as a measure of vegetation conditions in the study area. Remote-sensing data from 1981 to 2002 was extracted from composites of 10-day Advanced Very High Resolution Radiometer (AVHRR) data with a spatial resolution of 1.1 km. Sixteen-day MODIS NDVI data from 2002 to 2007 with a spatial resolution of 250 m was also used. The NDVI values are modified to range between –1 and +1 to make the analysis more convenient. MODIS NDVI data were re-sampled to 1.1 km to match with the spatial resolution of AVHRR NDVI data. The maximum value component was used to obtain the monthly and yearly data.

Aridity Index

An aridity index is an indicator used to characterizing the degree of aridity in a region, which in this case is characterized by the ratio of moisture and heat. De Martonne (1926) put forward a simple computational method to calculate an aridity index based on precipitation and temperature, using equation (1).

$$I_{dM} = P/(T + 10). \quad (1)$$

Where I_{dM} is de Martonne's aridity index, P is accumulated precipitation (mm) and T is average temperature (℃).

Livestock Density Data

Data on livestock numbers were converted into a uniform standard, using the standard sheep unit. Based on the 1:250,000 scale maps and other administrative maps, we calculated the annual spatial distribution of livestock using the Kriging interpolation method. We also considered the locations of residential areas and administrative division of towns. That is, for each area, we calculated the number of villages and towns in the area and we defined the area of weight coefficient as 0.5 for these area.

Results and Analysis

Correlation between NDVI and Aridity

Correlation analysis using ERDAS software was applied to the images of the spatial distribution of I_{dM} and NDVI, producing a spatial distribution of the correlation index (Figure 2). There was a positive relationship between NDVI and I_{dM} in the majority of the Xilingol area, except for in the Hunshandake Sandy Land and in the agro-pastoral transition zone in the southern part of the study area. Areas with correlation coefficients higher than the critical value of 0.31 accounted for 59.8% of the total area ($P < 0.1$), indicating that a significant positive correlation exists between moisture conditions and NDVI.

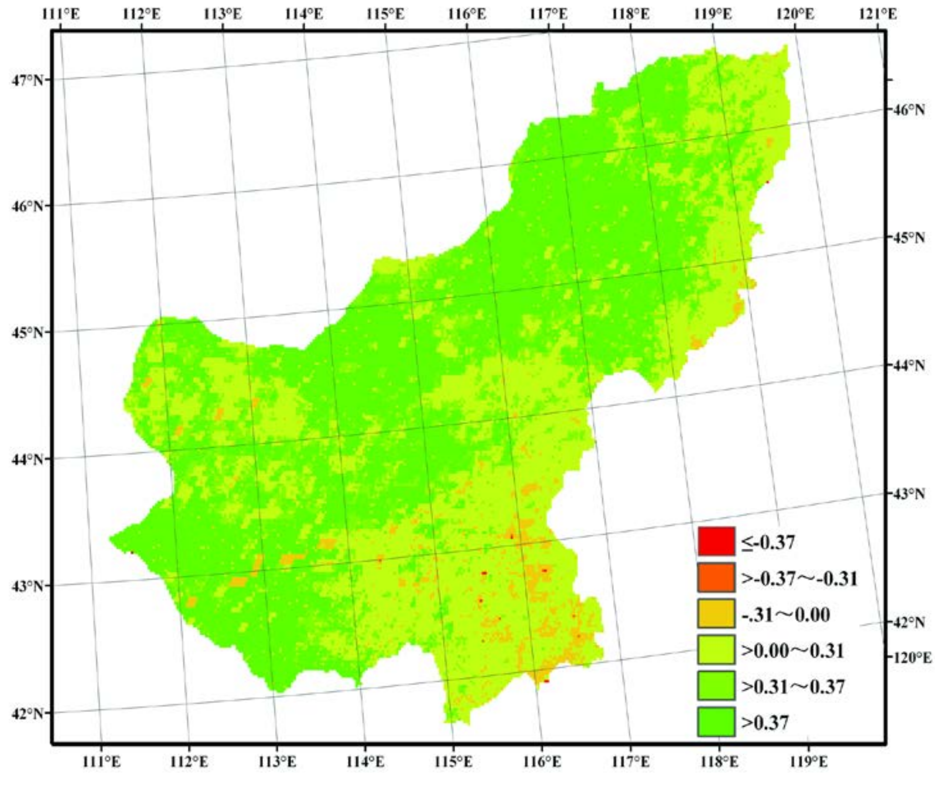

FIG. 2 CORRELATION BETWEEN ANNUAL NDVI AND DROUGHT INDEX (I_{DM}) IN XILINGOL FROM 1981 TO 2007.

Regression between I_{dm} and Vegetation Cover

Both vegetation cover and I_{dM} increased in bands running from west to east across Xilingol League. The relationship between I_{dM} and NDVI was also compared across three time periods representing the 1980s, 1990s, and the initial years of the 21st century (Figure 3). I_{dM} was classified into different classes using 2.5 as an interval. The classification was done separately for each image from the three time periods. In each time period, I_{dM} was derived for each class by averaging the I_{dM} for that class Mean NDVI for each time period was also calculated by averaging NDVI in the same aridity index (I_{dM}) class.

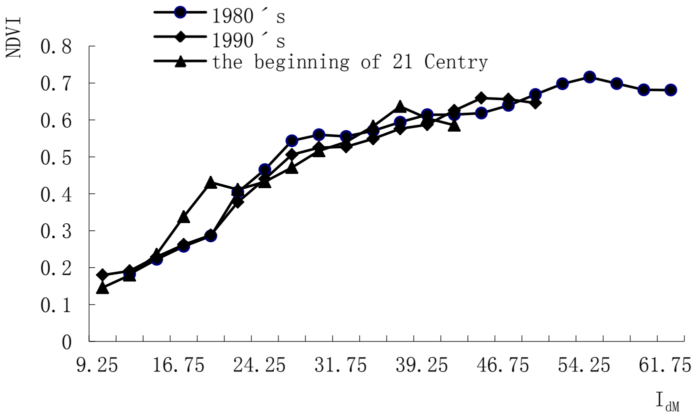

FIG. 3 THE RELATIONSHIP BETWEEN NDVI AND THE DROUGHT INDEX (I_{DM}).

Analysis revealed an obvious positive correlation between mean I_{dM} and NDVI for all three periods (Table 1).

TABLE 1 REGRESSION EQUATIONS BETWEEN NDVI AND ARIDITY INDEX (I_{DM}) IN THREE TIME PERIODS.

Equations / Periods	Equation	R2
1980s	y=2.4754x+8.9548	0.9997
1990s	y=2.4572x+6.6365	0.9996
the beginning of 21st century	y=2.4667x+6.4019	0.9994

Spatial Change in Livestock Density

Livestock density for the period 1981–2007 increased in bands from the northwest to southeast. The majority of Xilingol (53.2%) supported a livestock density of between 40–80 standard sheep units/km2. Livestock densities lower than 40 standard sheep units/km2 occurred in Erlianhaote, the northwestern part of Suniteyouqi and the northern part of Suniteyouqi. Livestock densities higher than 100 standard sheep units/km2 occurred in the southwestern part of Xiwuzhumuqinqi and the southeastern part of the research region in the agro-pastoral zone (Figure 4 (a)).

Compared with the 1980s, strong increases were seen in the 1990s in areas with a livestock density between 60–140 standard sheep units/km2, while the areas of livestock densities lower than 40, between 40–60, and higher than 140 standard sheep units/km2 decreased by 4.7%, 15.3%, 4.4%, respectively. Overall, livestock density increased in the 1990s (Figures 4 (b) and (c)). In the initial period of the 21st century, livestock density decreased sharply and livestock density was under 120 standard sheep units/km2 across the entire region. Compared with the 1980s and 1990s, livestock density of which areas lower than 40 and between 40–60 standard sheep units/km2 increased by 11.9% and 16.5%, respectively (Figure4(d)).

Livestock density is affected by a variety of human activities and by natural factors, including the climate. According to the analysis of the composite climate indicator (I_{dM}), climatic conditions in the 1980s and 1990s were better than in previous periods, although the initial period of the 21st century experience relatively poor climatic conditions, with more extreme drought caused by higher temperatures and low precipitation. Climate affected vegetation cover, and herders most likely changed their stocking levels to respond to changes in vegetation conditions. The macro policy of the Chinese government also affected stocking levels. Grassland and livestock contracting systems were implemented in the 1980s in China, with use rights to grassland reverting to the villagers, and the market influencing herders’ production decisions. The grassland tenure policy along with the use rights and contract responsibility system were implemented completely in the 1990s. With privatization of livestock, the number of livestock grazed increased greatly. The tenure, use right and contract responsibility system were mostly implemented in the early years of the 21st century, coupled with the implementation of transfer grazing and grassland enclosure policies. With the implementation of these policies, the use of grassland gradually transformed from extensive management to intensive management, and livestock density tended to be more reasonable.

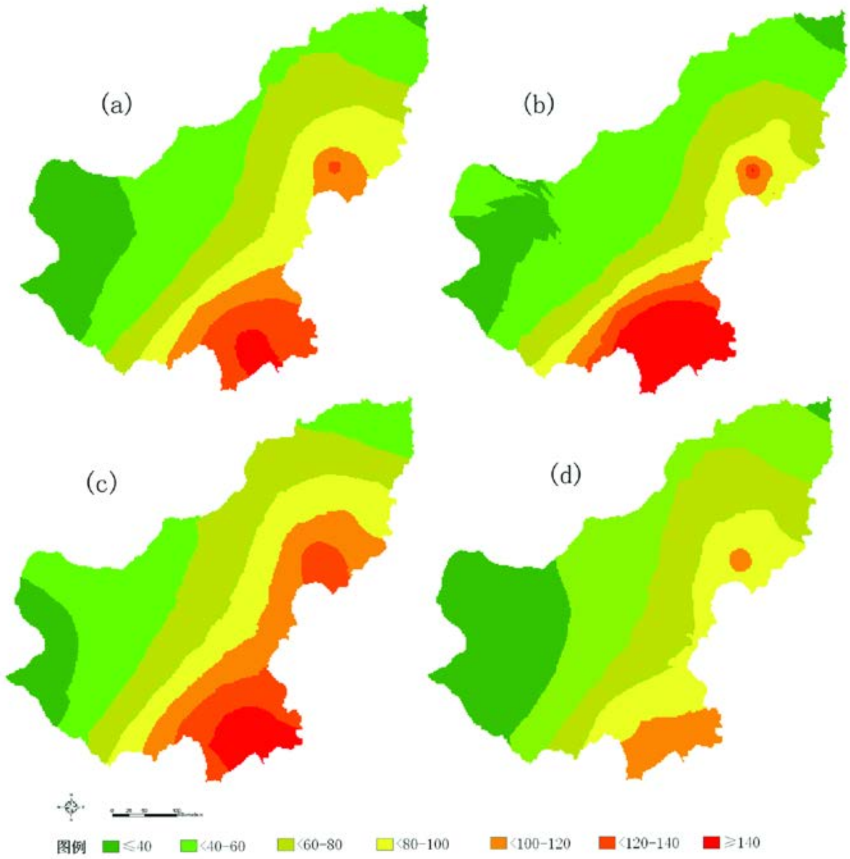

FIG. 4 SPATIAL DISTRIBUTION OF ANNUAL LIVESTOCK DENSITY IN XILINGOL: (A) FROM 1981 TO 2007; (B) FROM 1981 TO 1989; (C) FROM 1990 TO 1999; (D) FROM 2000 TO 2007.

Correlation between Vegetation Cover and Livestock Density

Based on the ten-day NDVI data from 1981–2007, we obtained the average image for every decade and classified each image into different classes using five as the interval for each class. Livestock density was derived for each class by averaging the NDVI that belonged to the same class. Mean livestock density for each time period was also calculated for each NDVI class. Regression analysis was applied to analyze the relationship between mean NDVI and mean livestock density in each time period (Figure 5).

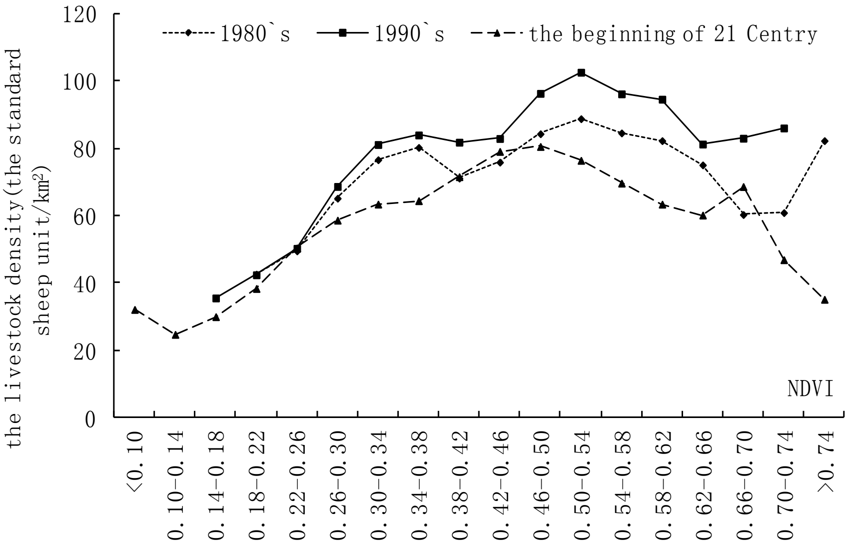

FIG. 5 RELATIONSHIP BETWEEN LIVESTOCK DENSITY AND NDVI IN THE STUDY AREA

Analysis revealed a binomial regression relationship between NDVI and livestock density in Xilingol League. With an increase in NDVI, livestock density first increased and then decreased. High livestock density was concentrated in areas with NDVI values ranging from 0.46 to 0.62. Table 2 provides the regression equations.

TABLE 2 REGRESSION EQUATIONS BETWEEN NDVI AND LIVESTOCK DENSITY DURING THREE TIME PERIODS

Equation / Period	Equation	R2
1980s	y=-0.5543x2+11.294x+25.626	0.7647
1990s	y=-0.5936x2+12.765x+4.6742	0.8676
the beginning of the 21st century	y=-0.6996x2+14.597x+18.946	0.9300

Mechanism of Vegetation Cover Change

Using the vector data delineating the boundaries of villages and towns and the annual data on aridity, livestock density, and NDVI, we obtained a binary linear regression equation using ArcGIS software, as shown in Equation. (2).

$$z = 113.019 + 3.596x - 0.131y. \tag{2}$$

Where z stands for NDVI, and x and y stand for I_{dM} and livestock density, respectively. The NDVI values are modified to range between 0 and 255 to make the analysis more convenient in this equation.

The equation has an R2 of 0.772, F = 113.622 and P = 0.000. This equation revealed a complex linear correlation existing among vegetation cover (NDVI), I_{dM}, and livestock density in the study region. The relationship between NDVI and moisture conditions is positive, while the relationship between NDVI and livestock density is negative. This indicates that vegetation cover is influenced by climate and overgrazing in Xilingol.

In order to determine which factor influenced NDVI the most, we did partial correlation analysis to measure multiple variables to determine the degree of linear correlation between two variables while using the other variables as controls. This provided a reasonable and reliable way to describe the linear connections between two variables.

The results of partial correlation analysis revealed a significant positive correlation between livestock density and I_{dM} (with a partial correlation coefficient of 0.811), which indicates that a more mesic environment can result in higher livestock stocking densities. A significant negative correlation was found between livestock density and NDVI (with a partial correlation coefficient of –0.336), while a positive correlation was found between the aridity index I_{dM} and NDVI (with a partial correlation coefficient of 0.706). Moreover, the influence of aridity on NDVI was considerably greater than that of livestock density.

Discussion and Conclusion

At present, research on the effects of grazing on changes in grassland vegetation cover has mainly been done using experimental tests in the study region. However, the spatial distribution of grazing is also influenced by the distribution of human settlements, the extent of livestock grazing activities and the policies in place in different locations. The distribution of livestock grazing is not uniform across the landscape, so at a large scale it will be difficult to explain spatial differences in the correlation between grassland conditions and grazing activities if conclusions are drawn based only on data from small-scale experiments. We were able to use spatial data on livestock populations with Kriging interpolation techniques, considering the number of villages and towns in an area to interpolate the spatial distribution of population density. Our analysis revealed how climate and grazing are driving changes in grassland condition, taking NDVI as a proxy for vegetation cover, in Xilingol League.

(1) In 1883, Dokuchaev proposed theories related to soil zone theory and the zonal pattern of the distribution vegetation, which have been developed into the most important fundamental theories in ecology. These theories have profoundly demonstrated the close relationship between the spatial distribution of vegetation and climate at both regional and global scales. The zonal distribution pattern of vegetation reflects the effect of climate on

vegetation development and distribution that is based on a long history of natural geographical phenomena. But within the time scale of a few years, with the current background of ongoing climate change, will there be a corresponding change in the relationship between growing conditions in this steppe region and climate change induced drought? The results of this study revealed a significant positive correlation existing between the mean I_{dM} and NDVI in three time periods. The spatial pattern of the relationship between NDVI and I_{dM} was positive in the majority of Xilingol League. That is, NDVI increases as moisture conditions improve, and decreases as moisture conditions decline.

(2) At present, the identification of the dominant factor causing change in grassland condition is still being debated. Hong Fuceng, the Group Chairman of the China Agricultural Expert Consulting China Grassland Honorary Chairman of the Society, thought that global climate change, in particular climate warming caused by the greenhouse effect, has exacerbated the current trend of widespread deterioration of the grassland environment. Also, human activity is another important factor affecting grassland degradation. Professor Ren Jizhou of the Chinese Academy of Engineering, Lanzhou University College of Pastoral Agriculture Science and Technology has said: "The causes of grassland degradation include natural and human factors, although human factors are the main factors" (2008). These comments reflect two aspects of the problem as seen by two experts, highlighting climate change and human disturbance as the main causes of grassland degradation. The results of this study can provide some insight into the possible effects of climate change-induced drought and grazing pressure on grassland degradation. There was a binomial regression relationship between vegetation cover and livestock density in Xilingol League. The relationship between NDVI and moisture conditions was positive, while the relationship between NDVI and livestock density was negative, indicating that spatial variation in vegetation cover in Xilingol is influenced by both climate and overgrazing. The results of partial correlation analysis revealed a significant negative correlation between livestock density and NDVI and a positive correlation between I_{dM} and NDVI. Aridity had a stronger influence on NDVI than livestock density.

ACKNOWLEDGEMENTS

The authors are grateful to anonymous reviewers for their constructive comments. This research is supported by the National Natural Science Foundation of China (Grant No. 40765006 and 30970494). Thanks to the project team for their hard work.

REFERENCES

[1] Anyamba, C.J. Tucker. Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981-2003. Journal of Arid Environments, 63(2005).

[2] C.J. Tucker, J.E. Pinzon, M.E. Brown, D.A. Slayback, E.W. Pak, R Mahoney, E.F. Vermote, N.E. Saleous. An extended AVHRR 8-km NDVI data set, compatible with MODIS and SPOT vegetation NDVI data. International Journal of Remote Sensing, 26 (2005).

[3] A.S. Hope, W.L. Boynton, D.A. Stow, D.C. Douglas. Interannual growth dynamics of vegetation in the Kuparuk River watershed, Alaska based on the Normalized Difference Vegetation Index. International Journal of Remote Sensing, 24, 17(2003).

[4] Z H Xia. The Studies on Dynamic of Vegetation Based on NDVI Time Series[D]. Beijing Forestry University, (2007)(Chinese).

[5] N Pettorelli, J.O. Vik, A Mysterud, J.M. Gaillard, C.J.Tucker, N.C. Stenseth. Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends in Ecology & Evolution, 20, 9(2005).

[6] M Glenn, E Robert, H Brian, R.F. David, H Jonathan, M Dana. Vegetation variation across Cape Cod, Massachusetts: environmental and historical determinants[J]. Journal of Biogeography, 29(2002).

[7] B R Chen, X P Xin, Y X Zhu, H B ZHANG. Change and analysis of annual desertification and climate factors in Inner Mongolia using MODIS data [J]. Remote Sensing Application, 6(2007)(Chinese).

[8] Z H Gu, J Chen, P JShi, M Xu. Correlation analysis of NDVI difference series and climate variables in Xilingole Steppe from 1983 to 1999 [J]. Acta Phytoecologica Sinica, 29, 5(2005)(Chinese).

[9] H Kobayashi, D.G. Dye. Atmospheric conditions for monitoring the long-term vegetation dynamics in the Amazon using normalized difference vegetation index. Remote Sensing of Environment. 97, 4(2005).

[10] K Ichii, A Kawabata, Y Yamaguchi. Global correlation analysis for NDVI and climatic variables and NDVI trends:1982-1990. International Journal of Remote Sensing, 23(2002).

[11] J Wang, P.M. Rich, K.P. Price. Temporal response of NDVI to precipitation and temperature in the Central Great Plains, USA. International Journal of Remote Sensing, 24(2003).

[12] Fabricante, M. Oesterheld, J.M. Paruelo. Annual and seasonal variation of NDVI explained by current and previous precipitation across northern Patagonia[J]. Arid Environ. 73, 8(2009).

[13] Cr Paltineanu, N Tanasescu, E Chitu, IF Mihailescu. Relationships between the De Martonne aridity index and water requirements of some representative crops: A case study from Romania. Int. Agrophysics. 21(2007).

[14] M Meng, J Ni, Z G Zhang. Aridity Index and Its Applications in Gep-Ecological Study. Acta Phytoecologica Sinica. 28,6(2004)(Chinese).

[15] Su-Bin Oh, Do-Woo Kim, Ki-Seon Choi, Hi-Ryong Byun. Introduction of East Asian drought monitoring system, SOLA, 6A, no. SpecialEdi, (2010).

[16] Y Z Tian, S P Chen, T X Yue, L Zhu, Y A Wang, Z M Fan, S N Ma. Simulation of Chinese population density based on Land use[J]. Acta Geographica Sinica, 59, 2(2004)(Chinese).